Factory-Made dry rendering mortars: Characterization and artificial weathering

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Abstract

The recent developments and the technological innovations undergone by the building industry, have significantly affected the field of render for external and internal walls. Thus, in the last decade, factory-made ready mixed dry render mortars and their mechanical application have been introduced in many countries with a consequent reduction of the application times and with a potential increase of the intrinsic render quality. A laboratory investigation has been conducted in order to evaluate the characteristics and the durability behaviour of some selected render systems chosen among those most frequently used in the Italian market. Six different general purpose rendering mortars, three of them based on hydraulic lime as binder and other three based on a mixture of hydrated lime and Portland cement were selected. In addition, a one-coat product also based on a mixture of hydrated lime and Portland cement and a reference mix prepared using natural hydraulic lime were also included.

The sample preparation was mainly made by the producers. For every product, at least three standard prisms (40x40x160 mm) were prepared, and two fired clay units of about 400 or 500x250x50 mm were employed as substrate on which a layer of render, about 20 mm thick, was applied using a spraying device. The samples were then stored for at least 28 days under different curing conditions, with temperatures varying from 20 to 23 °C, and relative humidities comprised between 50 and 98 %. The samples were then transported to the LTS laboratory where testing specimens were obtained by drilling cores out of the applied surfaces. For every product one prism and one of the prepared render samples were submitted to 33 artificial weathering cycles. Each cycle including the exposure of the sample to rain (20°C), freeze (-20°C), hot and moist (55°C, 95%r.h.) and warm and dry (30°C, 40%r.h.).

Although not all the producers did it, the determination of consistency, bulk density and air content on fresh mortar was foreseen for every mix. Tests on hardened mortar were performed both on unweathered and on artificially weathered samples. Bulk density, and flexural and compressive strength were determined on standard prisms, while bonding and compressive strength, porosity parameters, water absorption and water vapour permeability were determined on the drilled testing cores.

The results obtained show that, in general, the weathering cycles induce an increase of the values related to the mechanical properties. Regarding the physical properties it can be said that, while the weathering cycles induce a more or less significant increase in the values of the capillary water absorption coefficient, very little changes can be observed related to the capillary porosity values and, in general, no significant changes occur as far as the water vapour permeability is concerned.

Finally, further research work is needed in order to answer a basic question, which is: haw the weathering cycles affect the microstructure of the render in such a way that they produce an increase of the mechanical properties without any significant change in the porosity parameters and, at the same time, this is linked with an increase of the water absorption coefficient and, in some cases, also with an increase of the resistance to the water vapour diffusion?

Keywords: rendering mortar, durability, artificial weathering

1. INTRODUCTION

Significant technological progress has been achieved in many fields of the construction process in recent years. In particular, important changes have taken place in the field of rendering mortars for external use, where factory-made products and "new" application technologies have been introduced. As a consequence of these changes, a lot of products have successfully been introduced in the market and, although initially they were designed to be applied on newly constructed walls, they are increasingly used on historic buildings, not without creating certain perplexity among the specialists of the field of conservation. Factory-made production is a warranty of conformity and constant quality of the mortars, while the mechanical application allows shorter application times and, therefore, lower costs.

In order to characterize some of the factory-made render mortars most frequently used in the Italian market, but also with the purpose of evaluating their durability behaviour when submitted to artificial weathering in a climatic chamber, a laboratory investigation divided in two parts was undertaken. In this paper, we are reporting on the results obtained in the second part of this investigation, while the first part, regarding the characterization of the different products, will be published separately [1].

2. MATERIALS AND EXPERIMENTAL

2.1 Materials

A set of six manufacturers delivering in the Italian market were involved with their products and also, conducting partially the sample preparation. Six different general purpose rendering mortars [2], one from every manufacturer, were selected. Three of them were based on hydraulic lime as binder (mixes A1, A2 and A3) while the other three were based on a mixture of hydrated lime and Portland cement (mixes A4, A5 and A6). A one-coat rendering mortar produced by one of the previous manufacturers and based also on a mixture of hydrated lime and Portland cement (mix A7) and a reference mix prepared at the laboratory using natural hydraulic lime as binder (mix A8), were also included.

2.2 Sample preparation and curing

For every selected product, two fired clay units of about 400 or 500x250x50 mm were employed as substrate on which a layer of render, about 20 mm thick, was applied using a spraying device. Subsequently, the appropriate final coat was applied by the manufacturer to complete the system. As exceptions, the render type A4 and the render mortar prepared at the laboratory (A8) were applied manually, and the final coat of render type A2 was not applied by the manufacturer but at the LTS laboratory. In addition, for every mix, at least three standard prisms of 40x40x160 mm were also prepared by the manufacturers. However, the prisms of the mixes A2 and A8 were prepared at the LTS laboratory.

The samples were prepared at temperatures comprised between 20 and 25 °C and relative humidity values comprised between 50 and 70 %. After that, they were kept for 28 days under different curing conditions, varying from 20 to 23 °C temperature and from 50 to 98 % relative humidity. Mixes A2 and A5 were kept at the producers laboratory under uncontrolled conditions. The prepared samples were then transported to the LTS laboratory, where the testing specimens were obtained by drilling cores out of these applied render surfaces.

Mix A8 was prepared using a natural hydraulic lime binder and a commercially available, well graded aggregate with 2 mm maximum grain size. The preparation of the mixes was performed either following the standard procedure for the determination of the compressive strength of hydraulic cement mortars [3] or following the standard procedures related to the methods of test for mortars for masonry [4].

2.3 Testing programme

The determination of consistency, bulk density and air content on fresh mortar samples was foreseen for every mix [5, 6, 7]. However, as it can be seen in Table Nr. 1, not all the manufacturers did perform all these tests.

The tests on hardened mortar were performed both on unweathered and on artificially weathered samples. Bulk density, and flexural and compressive strength were determined on the standard prisms [3], while bonding and compressive strength [8, 9], porosity parameters [9], water absorption and water vapour permeability [10, 11], were determined on the drilled testing cores. Unless purposely specified elsewhere, every test was performed on three specimens.

2.4 Weathering cycle

From every mix, one prism and one of the prepared render samples previously described were submitted to 33 artificial weathering cycles. Each cycle covered a temperature range comprised between +55 °C and –20°C, and included the exposure of the samples successively to, periods of rain, 60 minutes at 20°C, freeze, 90 minutes at –20 °C, hot and moist, 60 minutes at 55°C and 95% r.h., and warm and dry, 80 minutes at 30°C and 40% r.h. for a total duration of 6.5 hours. Further details on the employed cycle can be inferred from [12].

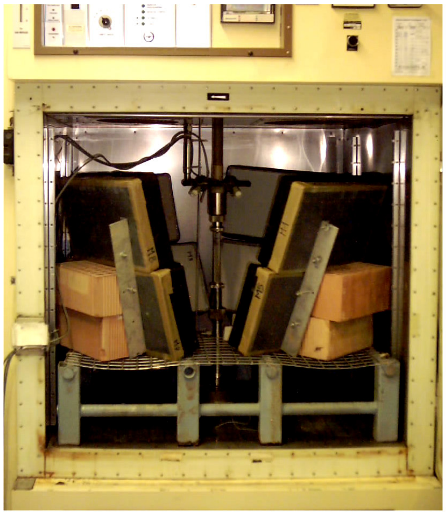

Figure 1. Climatic chamber showing the tested samples.

3. RESULTS AND DISCUSSION

3.1 Fresh mortar data

In Table Nr. 1 have been summarized the results on fresh mortar obtained and reported by the manufacturers. There it can be seen that the spread values are comprised between 155 and 196 mm and therefore all the mortars can be classified within the range of a plastic consistency.

The bulk density values of the commercial products are clearly lower than that of the reference mix (A8), while the values measured for the air content are higher for the commercial products. It has to be reminded that the reference mix was prepared without the use of any chemical admixture.

Render type	Spread [mm]	Bulk density [kg/dm^3]	Air content [volume %]
A1	-	-	-
A2	155	1.72	20.5
A3	170	1.90	-
A4	-	-	18.0
A5	167	1.77	17.0
A6	170	-	13.0
A7	-	-	-
A8	196	2.08	2.0

Table Nr. 1 – Fresh mortar data

3.2 Hardened mortar data

3.2.1 Standard prisms

In Table Nr. 2 it can be seen that the differences between the commercial products and the reference one, as far as the bulk density is concerned, are of the same order of magnitude as they were observed on fresh mortar.

Render type	Bulk density [kg/dm^3]	Flexural strength [N/mm^2]	Compressive strength [N/mm^2]
A1, unweathered	1.44	1.8	1.3
A1, artificially weathered	1.41	0.7	1.6
A2, unweathered	1.53	1.7	3.5
A2, artificially weathered	1.54	2.0	4.1
A3, unweathered	1.57	0.9	1.6
A3, artificially weathered	1.54	1.3	2.6
A4, unweathered	1.44	1.4	2.8
A4, artificially weathered	1.46	2.0	3.9
A5, unweathered	1.56	1.3	3.7
A5, artificially weathered	1.60	2.3	4.5
A6, unweathered	1.65	2.3	5.7
A6, artificially weathered	1.67	2.6	6.1
A7, unweathered	1.51	1.8	4.0
A7, artificially weathered	1.52	2.3	5.0
A8, unweathered	1.80	1.6	1.3
A8, artificially weathered	1.79	0.9	1.6

Table Nr. 2 – Physical and mechanical data obtained on standard prisms

However, as it could be expected, the absolute values are clearly lower in the hardened samples due to the water loss. Regarding the flexural and compressive strength values, it can be said that there is a relatively low variation among the different mixes for the former, and that the values are generally

higher in the mixes where the binder is based on a mixture of hydrated lime and Portland cement for the latter. Mix A2 can be considered as an exception to this assertion if we consider compressive strength as well as mix A3, if we consider flexural strength.
If we compare now the values obtained on the unweathered samples with those obtained on the artificially weathered ones, no general rule con be observed regarding the changes undergone by the bulk density, and in general, the changes are quite small. It has to be pointed out that some of the prisms submitted to artificial weathering showed clear signs of erosion, two of them (A1 and A8) having quite rounded edges, this making difficult a precise measurement of the prism sides and therefore, making also difficult a precise calculation of their volume. A different behaviour can be observed as far as flexural and compressive strength are concerned. The values of both properties generally show a clear increase by the artificially weathered samples, with increments going up to 76.9 % by the flexural strength (A5), and up to 62.5 % by the compressive strength (A3). Mixes A1 and A8 are two exceptions, where the values of flexural strength are clearly lower by the weathered samples. The prisms prepared with these two mixes were also the ones showing the most clearly visible erosion signs after 33 weathering cycles.

3.2.2 Applied render

3.2.2.1 Physical and mechanical properties

Table Nr. 3 shows the results related to bonding and compressive strength. The bonding strength values are relatively low and vary from 0.03 to 0.36 N/mm^2.

Render type	**Bonding strength [N/mm^2]**	**Compressive strength [N/mm^2]**
A1, unweathered	0.03± 0.02 B	0.66± 0.12
A1, artificially weathered	0.16± 0.01 B	1.83± 0.35
A2, unweathered	0.18± 0.10 A	4.91± 0.98
A2, artificially weathered	0.45± 0.02 A	12.88± 1.5
A3, unweathered	0.10* A	2.22± 0.16
A3, artificially weathered	0.51± 0.02 B	8.11± 0.41
A4, unweathered	0.21± 0.05 B	2.97± 0.46
A4, artificially weathered	0.29± 0.07 A	6.43± 1.4
A5, unweathered	0.10± 0.08 B	4.0± 0.75
A5, artificially weathered	0.18± 0.1 B	12.73± 0.93
A6, unweathered	0.36± 0.07 B	6.22± 1.13
A6, artificially weathered	0.42± 0.25 A	13.77± 0.93
A7, unweathered	0.12± 0.06 A	2.75± 0.44
A7, artificially weathered	0.27± 0.11 A	4.65± 0.39
A8, unweathered	0.03± 0.03 B	3.26± 0.69
A8, artificially weathered	0.11± 0.1 A	7.87± 0.64

Legend:
A = fracture surface at the interface render/substrate; B = fracture surface within the render layer
**) average of only two values*

Table Nr. 3 – Bonding and compressive strength data obtained on cores. Average and standard deviation.

In general, it can be seen that the weathering cycles induce an increase of the bonding strength. This increase is particularly consistent by the mixes based on hydraulic lime (A1, A2, A3, and the reference mix A8). While in the mix A3 the fracture surface moves from the interface render/substrate to the render layer, indicating an increase of adhesion, by the mixes A4, A6 and A8 the fracture surface moves from the render layer to the interface, probably indicating an increase of the tensile strength in the render layer.

The compressive strength values can also be considered as relatively low, while the mixes based on hydrated lime and Portland cement as binders show, mostly, higher values. If we compare now the values obtained on the unweathered samples with those obtained on the artificially weathered ones, we can see that the weathered ones show a clear strength increase, with increments going from 69.1 % (A7) to 265.4 % (A3) (Figure 2). The strength increase, surely due to a further hydration of the hydraulic compounds during the weathering cycles, seems to be much clearly pronounced by the mixes containing hydraulic lime as binder.

Comparing now the values obtained on the prisms with those obtained on the drilled cores, we can see that, with two exceptions (A1 and A7), the values obtained on the cores are higher, and that in both cases, there is a strength increase after the weathering cycles.

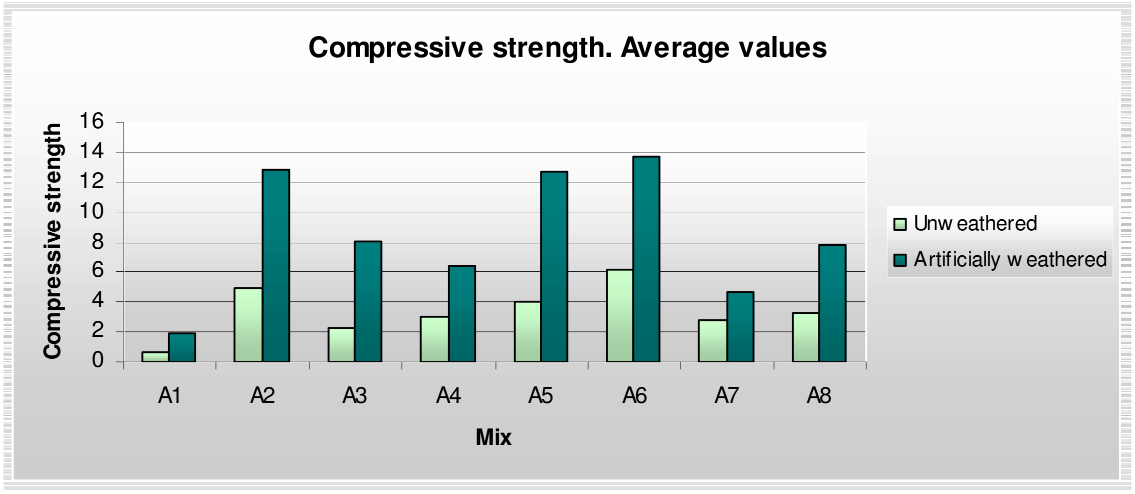

Figure 2. Compressive strength [N/mm^2]. Average values.

3.2.2.2 Porosity parameters

In Table Nr. 4 are reported some of the porosity parameters measured. There it can be seen that the capillary porosity values (U_E) vary between 21.7 and 30.1 volume %, with the exception of mix A7 for which, due to the presence of a water repellent agent in its composition, the measured values are lower than would be the “real” ones.

The air void porosity (n-U_E) values go from 9.6 to 18.2 volume % with two exceptions, mix A7 (30.0 %) and mix A8 (4.2 %). The high values measured reflect the use of air entraining chemical admixtures. Mix A7 shows higher values because, due to the presence of a water repellent agent, part of the capillary pores were filled only under vacuum saturation, and therefore, were assessed as air void pores. The lower values measured on mix A8 indicate the absence of air entraining agent in the mix. The total porosity (n) values correspond to the addition of the capillary porosity to the air void porosity.

Render type	Capillary porosity (U_E) [volume %]	Air void porosity (n-U_E) [volume %]	Total porosity (n) [volume %]
A1, unweathered	27.98±0.23	18.19±0.63	46.17±0.40
A1, artificially weathered	29.14±0.24	16.61±0.63	45.74±0.42
A2, unweathered	25.94±0.53	9.63±0.25	35.57±0.28
A2, artificially weathered	26.70±0.35	10.45±0.53	37.14±0.19
A3, unweathered	27.96±2.00	11.87±0.53	39.83±1.53
A3, artificially weathered	27.43±0.05	13.07±0.22	40.50±0.21
A4, unweathered	30.06±0.87	13.89±0.58	43.95±0.30
A4, artificially weathered	28.68±3.25	14.35±1.07	43.02±2.20
A5, unweathered	21.71±0.69	14.36±0.39	36.07±0.56
A5, artificially weathered	21.97±0.39	15.62±0.73	37.59±0.95
A6, unweathered	23.24±0.24	13.30±0.26	36.55±0.24
A6, artificially weathered	23.40±0.33	11.55±0.13	34.95±0.22
A7, unweathered	12.02±0.64*	30.04±0.32*	42.06±0.81
A7, artificially weathered	13.14±0.39*	28.80±0.25*	41.94±0.51
A8, unweathered	23.67±0.26	4.22±0.11	27.88±0.15
A8, artificially weathered	23.23±0.22	4.43±0.10	27.66±0.22

Legend:
**) Incorrect values due to the presence of a water repellent chemical agent in the mix*

Table Nr. 4 – Porosity data obtained on cores. Average and standard deviation.

The results obtained do not show significant changes when comparing the values obtained on the weathered samples with those obtained on the unweathered ones (Figure 3). The small variations observed can go both, towards a little increase of porosity or towards a little porosity reduction. Surprisingly enough, there is no relationship between increase of compressive strength and porosity changes.

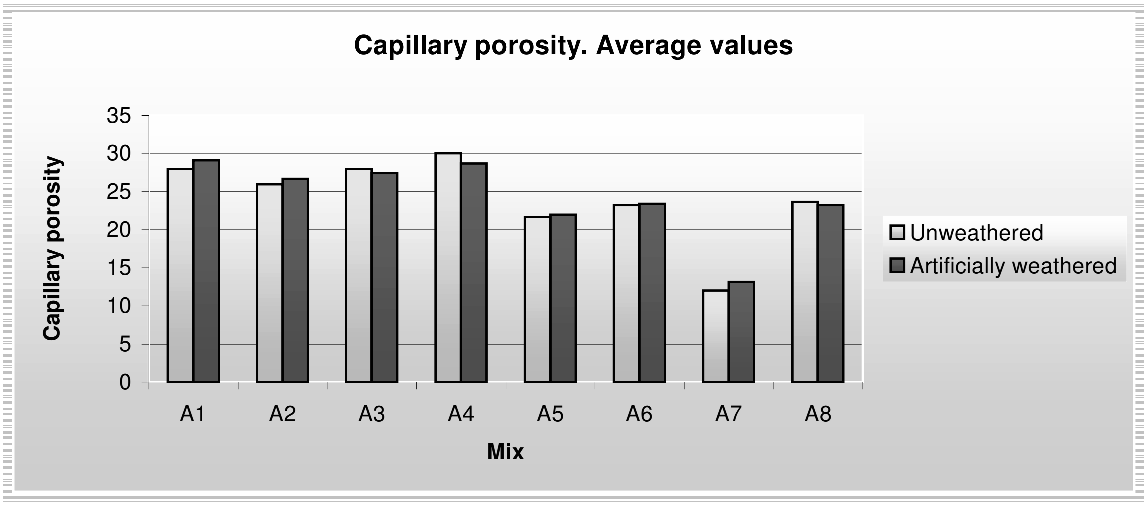

Figure 3. Capillary porosity [volume%]. Average values.

3.2.2.3 Water related properties

Looking at Table Nr. 5 it can be seen that the capillary water absorption coefficients are clearly different when comparing the mixes based on hydraulic lime with those based on hydrated lime and Portland cement as binder. While the former ones have values comprised between 4.07 and 5. 99 kg/m^2√h, the latter ones show values comprised between 0.62 and 2.50 kg/m^2√h. Mix A7, due to the presence of a water repellent agent in its composition, as mentioned, behaves clearly differently, and shows the significantly lower value of 0.2 kg/m^2√h. In general, it can be said that the weathering cycles induce a, more or less pronounced, increase of the water absorption coefficient (Figure 4). Mix A3 represents the only one exception to this common behaviour and shows a coefficient reduction.

Render type	**Capillary water absorption coefficient (W) [kg/m^2√h]**	**Factor of resistance to water vapour diffusion (μ) [-]**	**Thickness of the air equivalent layer (S_d) [m]**
A1, unweathered	5.07±1.00	11±0	0.19±0.01
A1, artificially weathered	5.27±1.14	10±1	0.20±0.02
A2, unweathered	4.07±0.27	26±2	0.22±0.01
A2, artificially weathered	5.58±0.31	19*	0.2*
A3, unweathered	5.99±0.72	18±1	0.21±0.03
A3, artificially weathered	3.76±0.21	29*	0.48*
A4, unweathered	0.62±0.03	18±1	0.30±0.02
A4, artificially weathered	2.60±0.52	19±2	0.37±0.05
A5, unweathered	2.23±0.15	21±1	0.29±0.01
A5, artificially weathered	3.09±0.22	20±2	0.28±0.03
A6, unweathered	2.50±0.04	24±1	0.36±0.01
A6, artificially weathered	2.92±0.06	25±2	0.39±0.02
A7, unweathered	0.20±0.03	18±1	0.33±0.02
A7, artificially weathered	0.38±0.07	16±1	0.29±0.01
A8, unweathered	5.4±0.21	25±1	0.58±0.01
A8, artificially weathered	6.92±0.25	34±2	0.85±0.04

Legend:
**) average of only two values*

Table Nr. 5 – Physical data obtained on cores. Average and standard deviation.

The general trend can also be observed by mix A7, where the coefficient value changes from 0.2 to 0.38, maintaining however its water repellent properties, with a value lower than 0.5 kg/m^2√h [13], and by the reference mix A8, which shows a moderate coefficient increase.

If we consider now the water vapour permeability of the mixes we can see that, while no significant differences can be distinguished looking at the factor of resistance to water vapour diffusion, some clear differences between mixes based on hydraulic lime and mixes based on hydrated lime and Portland cement appear, if the thickness of the air equivalent layer is taken into account (Figure 5). The values obtained lay around 0.20 m for the former mixes and around 0.30 m for the latter mixes. Mix A8 does not follow this trend, probably because the absence of entrained air voids.

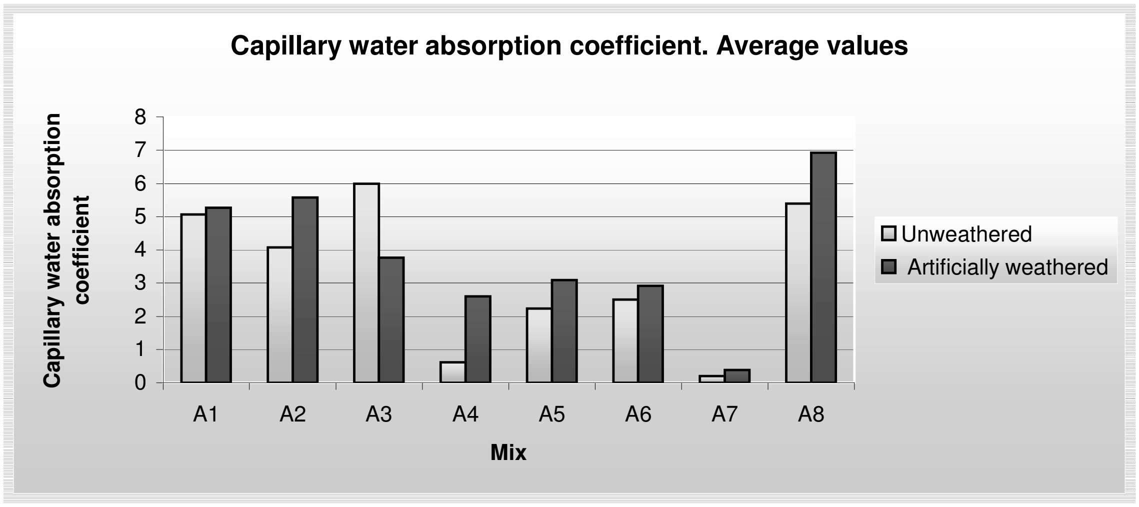

Figure 4. Capillary water absorption coefficient $\left[\frac{kg}{m^2 \cdot \sqrt{h}}\right]$. Average values.

With respect to the results obtained on the unweathered samples, only small changes can be observed looking at the results obtained on the weathered ones. However, two mixes (A3 and A8) do not follow the general trend, showing a clear increase visible both, looking at the resistance to water vapour diffusion and at the air equivalent layer, the former with values going from 18 to 29 (mix A3) and from 25 to 34 (mix A8), and the latter with values going from 0.21 to 0.48 m (mix A3) and from 0.58 to 0.85 m (mix A8). Mix A2 constitutes an exception showing a clearly visible reduction of the resistance factor, with values going from 26 to 19 and practically the same values as far as the thickness of the air equivalent layer is concerned, 0.22 versus 0.20 m.

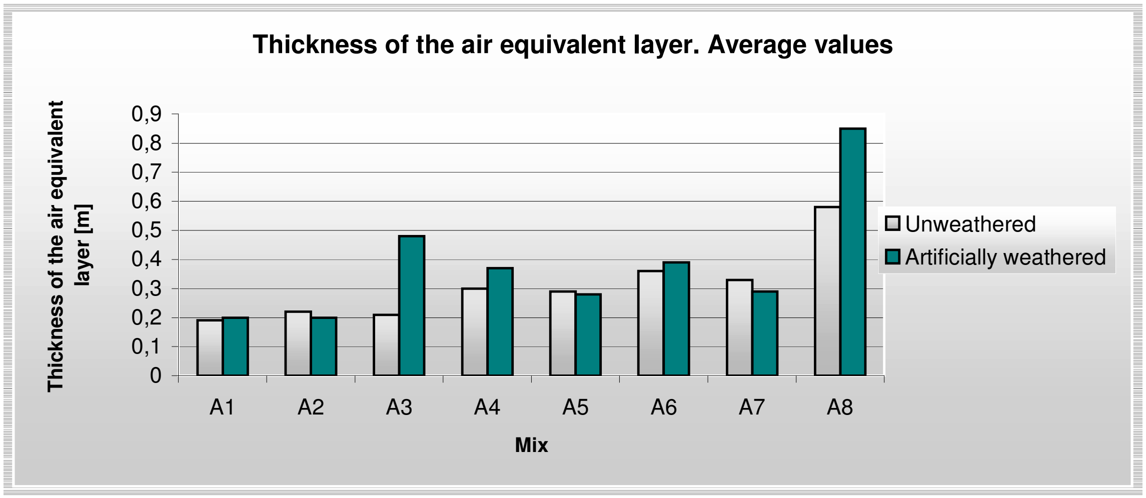

Figure 5. Thickness of the air equivalent layer. Average values.

These results are not in agreement with those obtained in a previous work [14], where a clear decrease of the capillary water absorption and a clear increase of the resistance to the permeability to water vapour were observed. However, it has to be pointed out that in the previous work the tested render mortar had a quite lower air void porosity due to the absence of air entraining agent in its composition.

4. FINAL CONSIDERATIONS

The results reported and discussed in the previous section allow several considerations. It can be observed, as a general rule, that the weathering cycles induce an increase of the values related to the mechanical properties. The strength increase can be explained assuming that, during the rain phase within the weathering cycle, the hydration reactions of the hydraulic binders undergo a further development. This increase of values by the mechanical properties, including the E-modulus, will probably result in a much brittle behaviour of the render, whose effects, due to the small size of the samples are not as clearly visible as they would be if larger areas were concerned. The observed differences between values obtained on prisms and values obtained on cores are known and have already been reported [15, 16], their origin however, has not been satisfactorily explained yet.

Taking now into consideration the physical properties it can be said that, while the weathering cycles induce a more or less significant increase in the values of the capillary water absorption coefficient, very little changes can be observed related to the capillary porosity values. This seems to indicate a change in the velocity at which water is absorbed into the render, without that any changes related to the total volume occupied by the capillary pores occur. Furthermore, although in general, no significant changes can be observed as far as the water vapour permeability is concerned; two samples clearly show a higher resistance to water vapour diffusion when submitted to the weathering cycles. Surprisingly, this variation is not connected with any significant change in the total porosity of those samples.

On the basis of the results obtained it can be said that the factory-made dry render mortars studied in this work, despite the different binder types used in their compositions, correspond to a good recipe concept, characterized on the one side, by relatively low compressive strength and, in comparison relatively high flexural strength values, and probably, also relatively low E-modulus values, and on the other side, by a balanced equilibrium regarding the behaviour with water, where a relatively high water absorption coefficient is linked with a high permeability to water vapour.

Summarizing, these overall characteristics lead to what can be considered as a good durability behaviour after the 33 weathering cycles, although, as we have seen, some significant changes towards a reduction of the performances are induced by the artificial weathering. However, this good behaviour would need a confirmation by a higher number of weathering cycles. Mix A7, characterized by the use of a water repellent agent in the recipe, has shown the best performances after the weathering cycles.

The results obtained in this work indicate, once again, that artificial weathering constitutes a very useful technique when the aim of an investigation is to compare the performance of different materials, in particular as in our case, of different render mortars. Much more difficult would have been to try to correlate the effects obtained with 33 cycles of artificial weathering with an equivalent natural weathering time, which was not the aim of this work.

Finally, some interesting questions that can be summarized in only one still remain open, and this basic question is: haw the weathering cycles affect the microstructure of the material, in such a way that they produces an increase in the mechanical properties without any significant change in the porosity parameters, and at the same time this is linked with an increase of the water absorption coefficient and, in some cases, also with an increase of the resistance to the water vapour diffusion? Further systematic research work involving the use of mortar test samples with different binder combinations and the application of more powerful techniques is still needed to answer this question.

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